Urban Forest Management Quantification Guidance

May 2016

1 Introduction

This document provides guidance for quantifying an Urban Forest Management (UFM) Project's Carbon Stocks[1], both for purposes of estimating a project's baseline as well as providing ongoing estimates of project Carbon Stocks throughout the Project Life. This guidance document is based on addressing important monitoring requirements. The specific monitoring objectives are to provide estimates of carbon inventories within the Project Area for purposes of calculating credits generated.

The Project Area must be defined prior to initiating inventory activities. Once defined, the Project Area may only be modified through agreement with the Climate Action Reserve (Reserve). Modification of the Project Area may impact the baseline, analysis of legal requirements affecting the Project Area, and other aspects of UFM Projects.

2 Reporting Requirements for Urban Forest Carbon Pools

Only Standing Live and Dead Trees can be included in quantifying UFM Project baselines and project estimates.

For standardized reporting, all estimates of forest Carbon Stocks must be provided in terms of tonnes (metric) of CO_2-equivalent (CO_2e) on a project and a per acre basis. Unless otherwise required in the referenced biomass equations, the following conversion formulae shall be used:

Table 2.1. Unit Conversions

Base Unit	Conversion		Final Unit
Biomass	.5 * biomass	=	Carbon
Carbon	3.67 * carbon		CO_2e
Kilograms	Kilograms/1000		Metric Tons (MT) or Tonnes
Tons	0.90718474 * tons		Metric Tons (MT) or Tonnes
Hectares	0.404686 * hectares		Acres

3 Methodologies for Estimating Current and Historical CO_2e in Urban Forest Management Projects

UFM Projects require a representation of the project's forest inventory in the past and at the Project Commencement Date. Project inventories must be updated, through the use of modeling as well as through the use of any field measurements that occurred since the previous reporting period on an annual basis for project monitoring. Only trees that are remeasured (DBH and height of all trees) within a maximum timeframe of 10 years are considered 100% inventoried. In cases where 100% inventories have been in place for at least the past 10 years, the historical inventory data can be used with the current inventory data to create the baseline trend (described below). Where trees are not 100% inventoried in UFM Projects, either in the current inventory or in the historic inventory, they must be sampled for the period in need of data. This quantification guidance provides sampling methodologies to develop urban forest inventories. Additional sampling methodologies may be added to this section as they are developed and reviewed by the Reserve.

[1] Capitalized terms are defined in the Urban Forest Management Project Protocol Version 1.0.

Sampling can be an efficient way to generate estimates of CO_2e in UFM Projects. The approach to estimating CO_2e for UFM Projects includes deriving a measurement of the canopy area within the Project Area and, through the use of ratio estimators developed through on the ground sampling of trees, deriving an estimate of CO_2e for the project.

The general approach to developing estimates of CO_2e in UFM Projects has the following steps, all of which are described in more detail in this section:

1. Stratify the Project Area into urban forest classes (optional).
2. Allocate and sample project plots.
3. Develop a ratio estimator (transfer function) of CO_2e estimates in standing live or dead trees.
4. Develop a measurement or estimate of the canopy cover in standing live or dead trees for each of the urban forest classes within the Project Area.
5. Multiply the transfer function by the total canopy cover measurement/estimate for each of the urban forest classes to estimate the CO_2e within each urban forest class.
6. Sum the estimates of CO_2e in standing live or dead trees for each urban forest class to develop an estimate for the project.

3.1 Stratifying the Project Area into Urban Forest Classes

Projects may choose to stratify the Project Area into the urban forest classes described in Table 3.1. The suggested urban forest classes below may be combined to form broader strata for sampling. For instance, the residential high density and residential low density forest classes may be combined to form a ‘residential’ category. There are no limits to how the Project Operator combines urban forest classes. Project Operators may also use project-specific characteristics to stratify the project area (e.g. classes based on tree management practices or growth conditions). The guiding requirement is that the confidence in the transfer functions generated through sampling meets or exceeds +/-20% at a 90% Confidence Interval for the combined strata. While stratification is optional, it can reduce the sampling error with fewer plots overall, and should be considered during project development.

If stratification is used, the result shall be a GIS layer for which the sum of the area of the polygons developed through stratification is equal to the Project Area sum and no areas within the Project Area are without an urban forest class identifier. The minimum mapping unit for stratification is 2 acres, which means no 2 acre contiguous unit shall be within a mapping polygon and labeled with a stratum that is clearly distinct from the stratum to which it is assigned.

Table 3.1. Suggested Urban Forest Class Labels and Descriptions

Urban Forest Class	Description
Commercial/Industrial Code = CI	In addition to standard commercial and industrial land uses, this category includes outdoor storage/staging areas as well as parking lots in downtown areas that are not connected with an institutional or residential use. Land use for utilities - such as power-generating facilities, sewage treatment facilities, covered and uncovered reservoirs, and empty stormwater runoff retention areas, flood control channels, and conduits - should also be classified as commercial/industrial. Note: For mixed-use buildings, land use is based on the dominant use, i.e., the use that receives the majority of the foot traffic. It might not always

	occupy the majority of space in the building. For example, a building with commercial use of the first floor and apartments on upper floors would be classified as Commercial/Industrial.
Institutional Code = IN	Schools, hospitals/medical complexes, colleges, religious buildings, government buildings, etc. Note: If a parcel contains large unmaintained areas, possibly for expansion or other reasons, treat the area as Open Space.
Open Space Code = OS	This category includes land with no clear immediate use, including natural forest stands that are not identified as parks. A natural forest stand can be identified as a forested area within the urban boundary that consists primarily of natural species, and has densities consistent with natural forest stands outside the urban area. Abandoned buildings and vacant structures should be classified based on their original intended use (e.g., commercial, institutional, etc.).
Residential Structures (Any Density) Code = RS	Residential structures serving one or more families, regardless of density.
Transportation Code = TR	Road right of ways where vehicle traffic commonly exceeds 45 miles per hour and vegetation management of the right of ways is distinct from the areas around it.
Parks Code = PS	Parks include undeveloped (unmaintained) as well as developed areas (but must be identified as a park). Small unmaintained areas within cemetery grounds should also be included in this stratum.
Agriculture Code = AG	Cropland, pasture, orchards, vineyards, nurseries, farmsteads and related buildings, feed lots, rangeland, timberland/plantations that show evidence of management activity for a specific crop or tree production are included.
Water/Wetland Code = WA	Streams, rivers, lakes, and other water bodies (natural or man-made). Small pools and fountains should be classified based on the adjacent land use.
Other Code = OT	Land uses that do not fall into one of the categories listed above. This designation should be used very sparingly as it provides very little useful information for the model. Clarify with comments in the Project Design Document (PDD).

3.2 Allocating and Sampling Project Plots

Transfer functions provide the ability to estimate the CO_2e in standing trees as a function of canopy cover. Transfer functions are developed from ground-based plots in which all trees in the plots are measured for variables that enable calculation of CO_2e estimates and canopy cover within the plot. This enables a ratio of CO_2e per unit area of canopy cover to be derived that can be applied to a measurement or estimate of canopy cover for each of the urban forest classes within the Project Area.

Project Operator’s must select between one of two methods for establishing sample points. Method 1 is based on a systematic approach to locating points. Method 2 is based on a random approach to locating points. The following sub-steps from either Method 1 or Method 2 are required to develop the transfer functions:

Method 1 – Systematic Allocation of Points

1. A grid of points spaced equally at 100 feet spacing across the Project Area must be created within the GIS map of the Project Area. Each point shall be attributed with latitude, longitude, and a unique identifier that is established in a sequential order within a database. Individual points will be selected from this set of points to serve as the basis for random sample locations of standing trees. A map of the point location and urban forest classes must be included within the PDD.

2. The points shall be grouped into sets within a database based on the urban forest class they are associated with, if applicable.

3. A subset of points shall be randomly selected from the sets of urban forest class/point combinations for sampling. Project Operators must provide a description of the random methodology used to select a subset of points. Alternatively, the Reserve provides the following suggested methodology:

   A list must be included in the PDD that displays the sets of points with their associated urban forest classes. Randomization shall be conducted by organizing the plots in separate lists in Microsoft Excel based on their associated urban forest classes using the following steps.

   A field shall be added and identified as plot/urban class number. A sequential value (1-n) shall be assigned to each plot. The Microsoft Excel function ‘randbetween’ shall be used with a minimum value of 1 and a maximum value set as the total number of plots in the plot/urban class association. In a separate added field, the order of random selection shall be identified until all of the plots are assigned a random value or a minimum of 100 plots are assigned a random value (whichever comes first). In the event a plot is selected more than once, the value assigned to the plot shall be the value of the first time it was selected.

Method 2 – Random Allocation of Points

1. The U.S. Forest Service’s i-Tree Canopy tool can be used as the basis of selecting random plot locations. The tool has additional utility in its ability to calculate canopy area (described below). The i-Tree Canopy tool will place randomized points within a user-defined area (Project Area). Project Operators must establish a minimum of 100 points, or a point for every 10 acres (whichever is smaller), in each of the strata initially. This step will likely result in more than the needed points being established in some strata. It is important to maintain the order of the location of the points as they must be visited in the field in the sequential order for each urban forest class.

The subset of sample points randomly selected in either of the two methods above is to be installed as fixed radius plots. The size of the radius from the plot center (from the point coordinates) is 37.25 feet (1/10th acre) or 24 feet (1/24th acre). Project Operators may explain and justify an alternative plot radius in the PDD. The radius must be consistently applied throughout the Project Life. Only the random plots selected need to be installed (and measured).

Project Operators must apply reasonable diligence to sample the selected random plots as they are ordered. Reasonable diligence means the Project Operator has made contact with the landowner, either through written or oral (telephone or onsite) media. Certain randomly selected points may be impossible to sample due to safety or accessibility and therefore must be rejected, as in cases where permission to trespass is not granted, either explicitly or indirectly through inadequate communication. Project Operators must wait a minimum of 10 days following the posting of letters to make a claim of inadequate communication, in the event the landowner fails to follow up with the Project Operator. A communication log with the landowner must also be maintained, detailing the phone calls and/or physical correspondence used to communicate.

Additionally, many points may not have any standing trees associated with them. Since the purpose of the sample plots is to develop a relationship between CO_2e and urban forest canopy, points with no trees within the radius described above can be rejected. When a plot is rejected for any reason, the reason for the rejection must be noted in a sampling log and included in the PDD. Project Operators must document the rationale for rejecting plots prior to selecting the next random plot in their list. In the event of plot rejection, the Project Operator shall select the next numerical point (1,2,3,…) in the plot list as a potential plot for measuring. In the event a successive plot is a plot that was already selected randomly, the Project Operator shall continue to the next plot (1,2,3,…) in the plot list. Any additional plots rejected over the Project Life must be noted in a project log and submitted with the annual monitoring report. The rejected plot log must be available for verification oversight.

Plot centers must be monumented so they can be relocated for future measurement or for verification. Monumenting plot locations so that they are available for re-measurement and/or verification can be challenging. GPS coordinates must be recorded for each plot at, or offset from, the plot center. Since GPS coordinates will only partially assist in relocating the plot center due to accuracy of GPS, additional navigational devices are necessary. It is recommended that, where possible, an object or marking be placed at plot center that is highly resistant to environmental features, including weather, animals, and fire.

However, the placement of a monument at plot center is not feasible in urban areas under most circumstances. Therefore, monumenting plot locations may require identifying features that can be used to triangulate to the plot center using distance and compass bearing measurements. Care should be used to ensure features are selected that are likely to endure up to 10 years. This might include building corners, fire hydrants, street signs, etc. Notes should clearly describe the feature being used as well as distance and bearing data. A minimum of two navigational features are required. It is recommended that the features be separated by at least 20 degrees to plot center.

Measurement standards and data requirements on each plot are outlined in Table 3.2.

Table 3.2. Measurement Standards for Urban Forest Sample Plots

For Each Plot		
Attribute	**Description**	
Date of Plot Visit	Day/Month/Year	
Latitude of Plot Center	From GPS	
Longitude of Plot Center	From GPS	
Navigational Feature 1 (optional if plot is monumented)	Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.	(Fire hydrant, street sign, building corner, etc.)

	Distance from feature to plot center	Feet
	Azimuth from feature to plot center	Degrees
Navigation Feature 2 (optional if plot is monumented)	Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.	(Fire hydrant, street sign, building corner, etc.)
	Distance from feature to plot center	Feet
	Azimuth from feature to plot center	Degrees
Stratum	If applicable, enter the Urban Class Code or user-defined stratum associated with the plot.	
Plot Number	Enter the plot number for the plot, as described in Section 2.2 above.	
Inventory Personnel	Enter the initials of the inventory technicians responsible for measuring and recording data on the plot.	

Measure all canopy area and all trees within a fixed 1/10th or 1/24th acre radius (radius = 37.25 feet or 24 feet, respectively) according to guidance below.

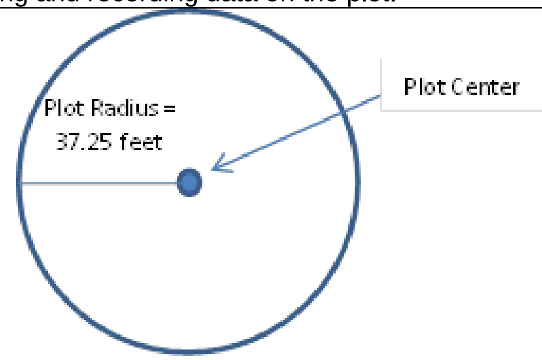
Radial measurements need to be corrected for horizontal distances:

1/10th acre fixed plot:

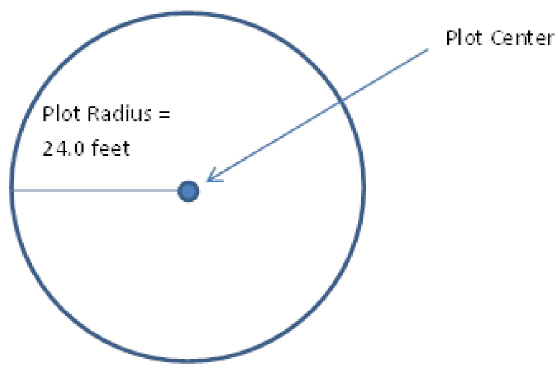
Slope %	5	10	15	20	25
Adj. Radius	37.30	37.44	37.67	37.99	38.40
Slope %	30	35	40	45	50
Adj. Radius	38.89	39.47	40.12	40.85	41.65
Slope %	55	60	65	70	75
Adj. Radius	42.51	43.44	44.43	45.47	46.56
Slope %	80	85	90	95	100
Adj. Radius	47.70	48.89	50.11	51.38	52.68

1/24th acre fixed plot:

Slope %	5	10	15	20	25
Adj. Radius	24.03	24.12	24.27	24.48	24.74
Slope %	30	35	40	45	50
Adj. Radius	25.06	25.43	25.85	26.32	26.83
Slope %	55	60	65	70	75
Adj. Radius	27.39	27.99	28.63	29.30	30.00
Slope %	80	85	90	95	100
Adj. Radius	30.73	31.50	32.29	33.10	33.94

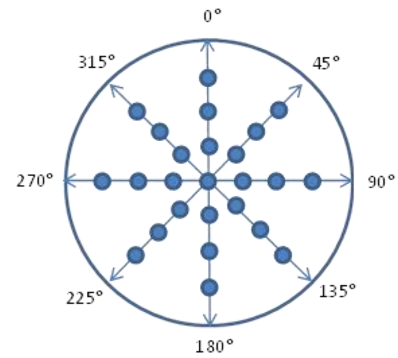


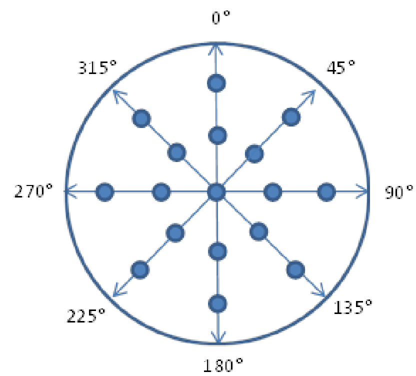
1/10th acre fixed plot



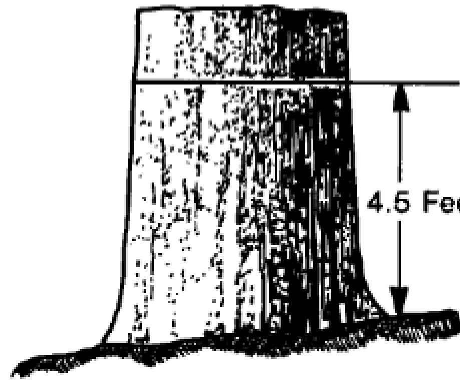
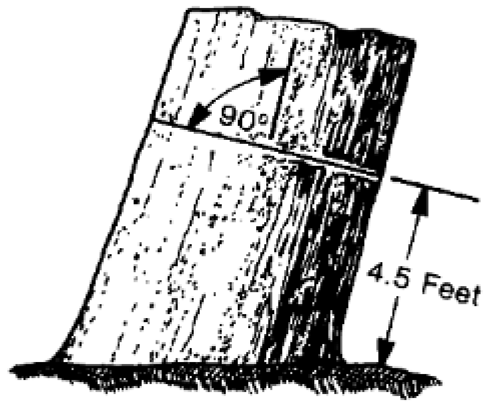
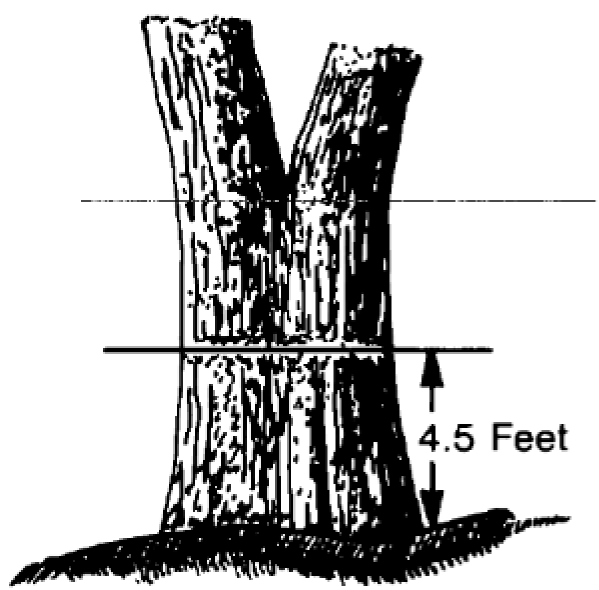
1/24th acre fixed plot:

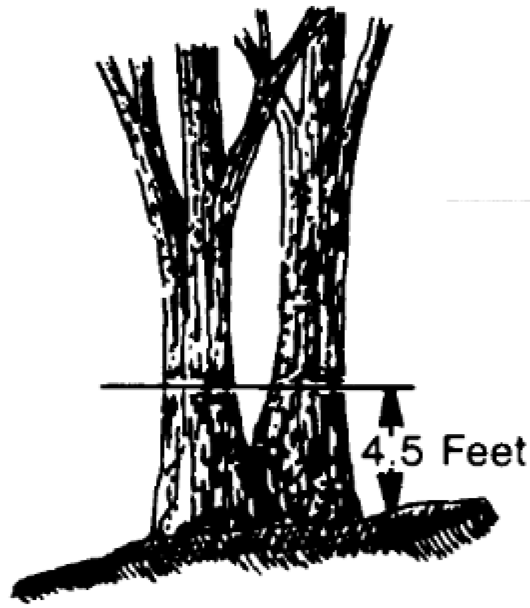
<table>
<tr><td>To determine canopy area, use a sighting tube at plot center and at 10 feet, 20 feet, and (if using a 1/10th acre plot) 30 feet from plot center on the compass bearings shown to determine a canopy ‘hit’ or canopy ‘miss’.

Multiply the sum of the hits by 4 to estimate the canopy cover percentage within the plot.</td>
<td>

1/10th acre plot


1/24th acre plot</td></tr>
<tr><th colspan="2">For Each Tree</th></tr>
<tr><th>Attribute</th><th>Description</th></tr>
<tr><td>Tree Number</td><td>Trees are assigned a number 1 to X starting from 0 degrees (North) and generally proceeding clockwise. The numbering convention facilitates the relocation and the verification of the trees.</td></tr>
<tr><td>Species</td><td>Enter the species code for each species on the plot. The species code can be found for each species in the corresponding biomass equation reference document. The species code is based on the first two letters of the genus and the first two letters of the species for any given species.</td></tr>
<tr><td>DBH</td><td>Measure and record Diameter at Breast Height (DBH) of all trees 3” DBH and greater to the nearest inch on every tree using a diameter tape and wrapping the tree at a height of 4.5 feet from the base of the tree on the uphill side.</td></tr>
</table>

	Forked trees above DBH are counted as one tree. Forked trees below DBH are counted as two trees (or however many forked stems exist). Add minimum DBH to be included. One tree

<table>
<tr><td></td><td>

Two trees

Images via FSH 2409.12 USDA Forest Service Timber Cruising Handbook</td></tr>
<tr><td>Total Height</td><td>Measure of total height (height from base of tree to top) of each tree to the nearest foot.</td></tr>
<tr><td>Growth Condition</td><td>An attribute of ‘Open’ or ‘Closed’ must be assigned to each tree according to the description below:
<table>
<tr><th>Class</th><th>Description</th></tr>
<tr><td>O</td><td>An open attribute is assigned to trees growing in non-natural settings. Tree species may be a variety of native and non-native species. Most often, trees exist in areas where disturbance of natural areas and conversion to another land use has occurred.</td></tr>
<tr><td>C</td><td>A closed attribute is assigned to trees growing in natural settings. Trees present are characteristic of the species diversity and structure in forested areas typically found outside the urban area.</td></tr>
</table></td></tr>
<tr><td>Vigor</td><td>For each tree, provide a rating of the tree’s apparent vigor. Determination of vigor based on consideration of color of foliage, crown proportion and appearance, retention of leaves/needles, appearance of apical growth, length between growth whorls, and presence of cavities and fungal growth. The code is assigned based on the following classes:
<table>
<tr><th>Code</th><th>Description*

*Based on conditions present during growing periods. Professional judgment need be applied if sampling conducted outside of growing periods.</th></tr>
<tr><td>1</td><td>**Excellent** – Tree exhibits high level of vigor and no barriers (soil, light, etc.) to continued vigor. No decay or broken</td></tr>
</table></td></tr>
</table>

		branches are observed.
	2	**Good** – Tree exhibits high level of vigor and some minor barriers (soil, light, etc.) to continued vigor. No decay or broken branches are observed.
	3	**Fair** – Tree appears generally healthy. Barriers (soil, light, etc.) affect the tree's vigor. Tree's crown may be smaller proportionally than in healthier trees. Decay and/ or broken branches, if observed, are not likely to have negative impacts in the short term.
	4	**Poor** – Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have high likelihood of being rectified through management of said tree and trees surrounding it.
	5	**Critical –** Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have low likelihood of being rectified through management of said tree and trees surrounding it.
	6	**Dying –** Tree is unhealthy. Minimal live crown is present; portions of bark may be missing and/or substantial levels of broken stems and branches. Tree may exhibit advanced decay. No further investment in restoring the tree to a higher vigor is deemed worthwhile.
	7	**Dead –** No live material is observed in the tree. Trees with this attribute will be used to quantify SSR3 – Standing Dead Wood.
Defect – Bottom 1/3 Defect – Middle 1/3 Defect – Top 1/3	For each portion of the tree (based on total height), provide an ocular estimate of the portion of tree that is missing (as a percentage of the section) as the result of breakage or cavities.	
Decay Class	Decay Class	Description of Condition of Standing Dead Wood
	1	All limbs and branches are present; the top of the crown is still present; all bark remains; sapwood is intact with minimal decay; heartwood is sound and hard.
	2	There are few limbs and no fine branches; the top may be broken; a variable amount of bark remains; sapwood is sloughing with advanced decay; heartwood is sound at base but beginning to decay in the outer part of the upper bole.
	3	Only limb stubs exist; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay in upper bole and is beginning at the base.
	4	Few or no limb stubs remain; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay at the base and is sloughing in the upper bole.
	5	No evidence of branches remains; the top is broken; less than 20 percent of the bark remains; sapwood is gone; heartwood is sloughing throughout.

3.3 Quantifying CO_2e Estimates in Standing Trees at Sample Plots and Developing Transfer Functions

3.3.1 Calculating Above and Below-Ground Carbon

1/10th or 1/24th acre plots shall be measured in each urban forest class. The tree canopy shall be measured as shown in Table 3.2 above. The percent estimate derived from the plot shall be multiplied by 43,560 to provide an estimate of the canopy cover represented by the plot in square feet per acre. CO_2e shall be calculated for each tree using the appropriate biomass equations provided by the Reserve on the Urban Forest Project Protocol website (for trees in natural forest stands within the project area, refer to the biomass equations approved for use with the Forest Project Protocol). The biomass equations enable calculation of CO_2e for the above-ground portion of trees, using the units of conversion provided at the top of this section. The below-ground portion of trees shall be calculated by multiplying the above-ground portion of trees by 26%. This should be done for all trees in the project area (including natural forest stands). This value shall be added to the above-ground portion to produce a value that represents the above and below-ground tree.

3.3.2 Accounting for Defect in Standing Dead and Live Trees

Both standing live trees and standing dead trees may be missing portions of the tree as the result of physical and biological disturbances. Tree biomass needs to be adjusted for missing parts to produce an improved estimate of the tree's biomass. Calculating CO_2e in standing dead trees raises additional challenges since they may be in stages of decay such that density equations in standard biomass equations for live trees do not provide an accurate estimate. The guidance in this section provides a standardized method to account for biomass adjustments.

The first step is to estimate the gross biomass in the tree as if it were whole, using the biomass equations provided on the Reserve's Urban Forest Project Protocol webpage (or Forest Project Protocol webpage for natural forest stands). The tree's biomass is then adjusted based on the tree's 'net' biomass and adjusted density estimates for standing dead trees. To standardize, the tree is divided into four parts: top, middle, bottom (visually estimating the original disposition of the above-ground portion of the tree when it was alive and vigorous), and the below-ground portion. The below-ground portion must be calculated as 26% of the gross above-ground portion of the tree. It is assumed that the below-ground portion is intact and complete. The standardized percentages assumed to be in each portion of the tree are shown in Table 3.3.

Table 3.3. Assumed Percentages of Biomass in Each Portion of the Tree

Tree Portion	Percent of Tree Biomass
Top 1/3	10%
Middle 1/3	25%
Bottom 1/3	65%

An ocular estimate is made of the portion remaining in each section of the tree during field sampling, as described in Table 3.2. Deductions from gross biomass (or gross volume) are made for anything that reduces the tree's gross biomass, including breakage and cavities. The percentage remaining in each third is then summed to calculate the net biomass remaining in the tree.

For standing dead wood, the tree's density must be adjusted to account for the varying states of decay in the remaining portion of the tree. Because standing dead wood does not have the same density as a live tree, a density reduction must be applied. Standing dead wood may fall into five decay classes, which must be recorded during the field sampling. The five decay classes, described in **Error! Reference source not found.**Table 3.2, are qualitative, based on the physical characteristics of the dead tree.[2]

The density identified for each species in the biomass equations must be modified for decay classes 2 to 5 using the reduction factors displayed in Table 3.4.[3]

Table 3.4. Average Density Reduction Factors for Standing Dead Wood for Hardwoods and Softwoods by Decay Class

Softwoods		Hardwoods	
Decay Class	**Reduction Factor**	**Decay Class**	**Reduction Factor**
2	1.0	2	0.8
3	0.92	3	0.54
4	0.55	4	0.43
5	0.29	5	0.22

An example of field data that has all of the required elements for calculating the standing dead tree's CO_2e is shown in Table 3.5.

Table 3.5. Example: Data Attributes Needed to Calculate CO_2e in Standing Dead Trees

Tree Number	Species Code	DBH (inches)	Height* (feet)	Growth Condition	Vigor	Percent Remaining			Decay Class
						Top 1/3 of Tree	Middle 1/3 of Tree	Bottom 1/3 of Tree	
1	UGEC (urban general conifer)	16	95	O	7 - Dead	0%	50%	100%	3

The density of the tree must be adjusted based on its decay class. The first step is to calculate the tree's biomass as if the tree were a normal tree to determine the tree's gross biomass. Net biomass is determined by multiplying the gross biomass of the tree by the reduction factor displayed in Table 3.4. An example is provided in Table 3.6.

[2] USDA 2007, Woundenberg et al., 2010
[3] Harmon et al, 2011. Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Res. Pap. NRS-15. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 40 p.

Table 3.6. Example: Adjusting Biomass Calculation for Decay Using Density Adjustment Factors

Tree Gross Biomass	Density Reduction Based on Decay	Net Biomass
(tonnes CO_2e) (assumed)	(from Table 3.4 for a softwood with a decay class '3')	(tonnes CO_2e) (assuming tree is whole)
0.100	0.92	0.092

As an example of the application of the biomass deductions for missing sections of the tree, using the data from Table 3.5 above, a tree (assuming normal form) with a net biomass of 0.092 CO_2e tonnes would be further adjusted to a net biomass for the missing portions of the tree as shown in Table 3.7.

Table 3.7. Example: Calculating Net Biomass in a Tree

Tree Portion	Percent of Tree Biomass	Gross Biomass	Percent Remaining in Tree	Net Biomass
	(from Table 3.3)	(tonnes CO_2e) Percent of tree biomass **x** tree biomass adjusted for density (Table 3.6)	(from example in Table 3.5)	(tonnes CO_2e) Percent remaining in tree **x** gross biomass
Top 1/3	10%	10% **x** 0.092 **=** 0.0092	0%	0.00000
Middle 1/3	25%	25% **x** 0.092 **=** 0.023	50%	0.00115
Bottom 1/3	65%	65% **x** 0.092 **=** 0.0598	100%	0.0598
Total Biomass				0.0713

3.3.3 Developing Transfer Functions

These values shall be summed for each plot and multiplied by 10 or 24 (according to whether 1/10th or 1/24th acre plots are used) to establish a per-acre estimate from each plot. All values shall be presented as metric tonnes CO_2e per acre.

The average canopy cover (per-acre basis) and the average CO_2e value (per-acre basis) from all measured plots shall be calculated and documented in the PDD. A ratio of CO_2e per square foot of canopy cover shall be calculated, as shown in Table 3.8.

Table 3.8. Urban Forest Class and Transfer Functions

Urban Forest Class	Average Canopy Cover Area from Ground-Based Plots	Average CO_2e from Ground-Based Plots	Transfer Functions
	(ft^2/acre)	(per acre)	(CO_2e/ft^2 of canopy cover)
Commercial/Industrial	3,485	15	0.0043044
Institutional	5,227	20	0.0038261
Residential Structures	15,246	60	0.0039355
Transportation	3,485	12	0.0034435

3.4 Measuring or Estimating Current Canopy Cover in Standing Trees for Each Urban Forest Class within the Project Area

The total canopy of trees must be measured or estimated for each of the urban forest classes using remotely sensed data throughout the project area. If measured, the entire canopy cover for the Project Area will be mapped as a layer in a GIS. The data and tools used to measure the canopy area are not limited and may include a variety of remotely sensed data and automated digitizing, as well as manual digitizing. Any tools and methodologies used to develop the GIS layer of canopy will be reviewed by the verifier for statistical accuracy and appropriateness.

If the canopy layer is sampled rather than measured, the sampled portion must be displayed as a layer in a GIS. The following methods are allowed for sampling canopy area:

1. Randomized points developed using the i-Tree Canopy tool derive a ‘hit’ or ‘miss’ (of tree canopy), and must be determined by the technician. The proportional points superimposed on canopy allow a percentage and confidence statistics to be calculated. The percent estimate is applied to the area of each stratum within the Project Area to determine a canopy area estimate for each stratum. i-Tree Canopy does not currently allow the user to calculate canopy percentages independently for each stratum. Therefore, the Project Operator must attribute each point to the stratum it is in and calculate the percentages and confidence statistics independently from the i-Tree Canopy tool.

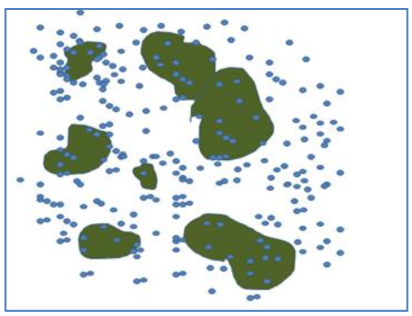


Figure 3.1. Example of Overlaying Random Points in the Project Area to Determine Canopy Percentage

2. A systematic sample can be conducted with a grid of points established in a GIS and placed over the Project Area for the purposes of estimating canopy area. The Project Operator must determine the ‘hit’ and ‘miss’ of each point (in terms of being coincident with a/multiple tree crown(s)), which will enable a percentage to be determined and canopy area to be determined (as described above).

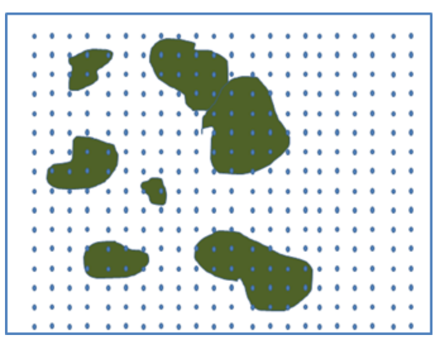


Figure 3.2. Example of Overlaying a Systematic Grid in the Project Area to Determine Canopy Percentage

3. Sampling can be conducted using remotely sensed data as a subset of the Project Area. Again, the sampling must be designed to develop estimates for each stratum independently. The sampling must incorporate randomized strips (two parallel lines with a known distance between them to calculate area) or randomized or systematic area plots. The Project Operator must be able to calculate accurately the area within the strip or plot that is tree canopy and the area that is not tree canopy.

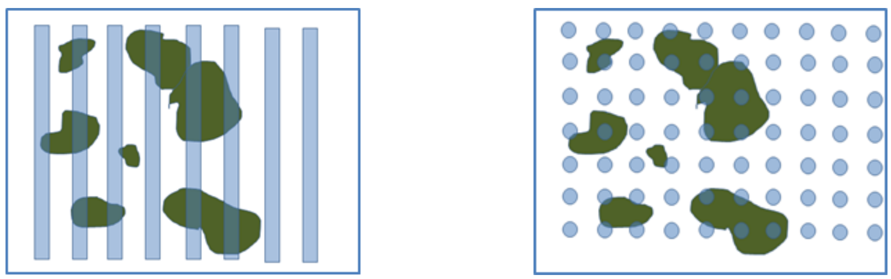


Figure 3.3. Example of Overlaying Known Area Sampling Units (Strips and Fixed Radius)

Regardless of the method utilized:

1. The points, strips, or plots must be maintained for the Project Life and be available for verification.

2. Sampling for canopy cover must continue until a confidence estimate for average canopy cover for each urban forest class is achieved at +/-10% at a 90% confidence interval. A list of plots sampled and each plot's estimated percentage and canopy area estimate must be included in the PDD.

3. A table must be presented in the PDD that provides the data shown in Table 3.9 Data shall be carried out to two decimal points. If the canopy was 100% measured, the canopy area can be entered directly into the table below. If sampled, the mean percent canopy estimate from sampling is multiplied by the area within each urban forest class to estimate the canopy area.

Table 3.9. Example of Canopy Cover Data Required in Project Area

Urban Forest Class/Stratum	(A) Mean Estimate of Canopy Cover at 90% CI[1]	(B) Total Area within Project Area[2] (acres)	(C) Total Area of Tree Canopy within Project Area (acres)	(D) Total Area of Tree Canopy within Project Area (ft^2)
Commercial/Industrial	10.60%	50.45	5.35	233,046.00
Institutional	17.71%	10.56	1.87	81,457.20
Residential Structures	34.89%	155.67	54.32	2,366,179.20
Transportation	6.80%	67.23	4.57	199,069.20
Total	21.13%	283.91	60	2,613,600.00

[1]Enter value based on sampling. If total canopy cover area is directly measured, this step can be skipped and the final values may be reported.
[2]Area measured based on chosen method for stratification.

In the example shown above, column A represents the canopy cover estimate derived using one of the methods described in Section 3.3 above. This is broken down by urban forest class or stratum, if the project has chosen to stratify. The value in column B represents the total size of that class or stratum. Column C (the total area of tree canopy within the project area) is generated by multiplying column A by column B. Lastly, this value is multiplied by a factor of 43,560 to convert to ft^2, which provides the result for column D. These final numbers are then used to calculate project CO_2e, as described below.

3.5 Using Default Transfer Functions

Project developers may propose to use local, state, or federal transfer functions, if available. The Reserve should be contacted for approval of any pre-determined transfer functions or ratio estimators. The Reserve will also make available a list of approved transfer functions on its website.

3.6 Determining the Current Project Area Estimate of CO_2e

With the total tree canopy area estimated or measured and transfer functions developed for each of the urban forest classes, an estimate of CO_2e for the Project Area can be estimated. The transfer functions are multiplied by the total square feet of canopy cover in each urban forest class and summed to determine the estimated CO_2e in the Project Area, as shown in Table 3.10.

Table 3.10. Example of Expanding Transfer Functions Based on Canopy Cover Area to Estimate Total Current CO_2e within the Project Area

Urban Forest Class	Transfer Functions (from Table 3.8)	Current Estimated/Measured Canopy Cover Area (from Table 3.9, or measured)	Total CO_2e
	(CO_2e/ft^2 of canopy cover)	(ft^2)	(metric tons)
Commercial/Industrial	0.0043044	233,046.00	1,003.12
Institutional	0.0038261	81,457.20	311.66
Residential Structures	0.0039355	2,366,179.20	9,312.10
Transportation	0.0034435	199,069.20	685.49
		Total	11,312.38

3.7 Calculating the Historical Project Area Estimate of CO_2e

A historical inventory is required to develop a trend used in the development of the project baseline. The historical Project Area estimate of CO_2e is calculated by expanding the transfer functions developed for the current inventory data using canopy cover estimates from remotely-sensed data that was produced at least 10 years prior to the image used to produce the current canopy cover estimate. The trend line must pass through two points of inventory estimates that are at least 10 years apart and with the earliest point no earlier than 1990.

It is acceptable to either measure the entire canopy area from an earlier image or to sample the canopy area, using the method described in Section 3.4. The analysis of plot area shall terminate upon completion of the same plots sampled for the current inventory estimate. The image(s) used must be available to a verifier and identified in the PDD. An example of using a historical estimate of canopy cover to expand transfer functions in order to calculate a historical CO_2e estimate is shown in Table 3.11.

Table 3.11. Example of Expanding Transfer Functions Based on Historical Canopy Cover Area to Estimate Historical CO_2e within the Project Area

Urban Forest Class	Transfer Functions (from above) (CO_2e/ft^2 of canopy cover)	Historic Estimated/Measured Canopy Cover Area (ft^2)	Total CO_2e (metric tons)
Commercial/Industrial	0.0043044	201,222.00	866.14
Institutional	0.0038261	79,566.00	304.43
Residential Structures	0.0039355	2,375,898.20	9,350.35
Transportation	0.0034435	168,951.20	581.78
		Total	11,102.70

3.8 Developing the Baseline for Urban Forest Management Projects

The baseline for UFM Projects is calculated by developing a trend based on a comparison of two sets of historical estimates of Standing Live and Dead Trees and /or a comparison of historical estimates of Standing Live and Dead Trees to current estimates. The slope developed by plotting the two points of inventory on their respective year of reporting is continued into the future for the next 20 years and then held steady for the subsequent 80 years where legal requirements have not been modified substantially, as described below.

An analysis of legal requirements must accompany the baseline development. The PDD must include a full disclosure of legal requirements affecting tree management within the Project Area, as well as a narrative describing the analysis of these requirements. Any substantial change in legal requirements, including ordinances, regulations, or other legal obligations, not including legal obligations associated with the use of this protocol, that would modify the trend described above over the next 20 years must be modeled for the next 20 years or as long as stated in the requirements (whichever is longer). Modeling is conducted by projecting any carbon stored by trees obligated by the regulation forward into time. Modeling must be conducted by a Certified Arborist, a Certified Forester, or a Professional Forester. Where modeling must be conducted, the baseline shall be defined by a straight line from the UFM Project's initial stocks to the highest point determined from baseline modeling. Examples of sources of legal obligations may include, but are not limited to, tree ordinances, urban forest ordinances or management plans, landscaping ordinances, or other environmental regulations associated with urban development and land use change. Refer to Section 3.5.1 of the protocol for more information on requirements regarding legal requirements.

Examples of the baseline approach, assuming a project commencement in 2015, are displayed in Figure 3.4 and Figure 3.5.

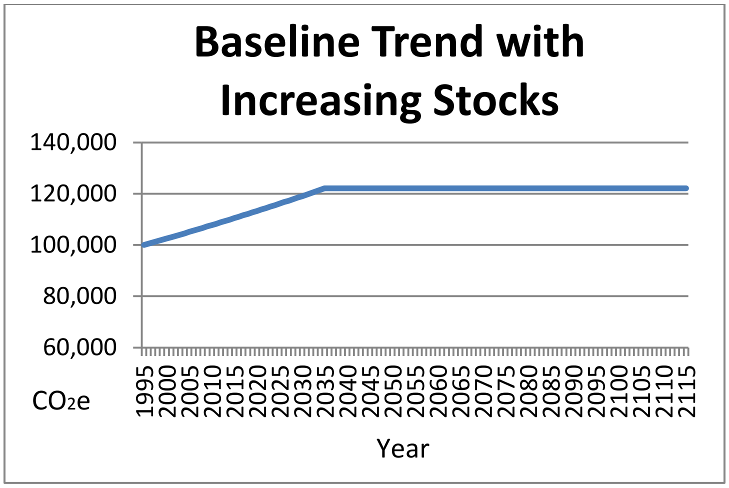


Figure 3.4. Example of Increasing Baseline Trend Extending 20 Years Beyond Current Inventory and then Static for Balance of 100 Years

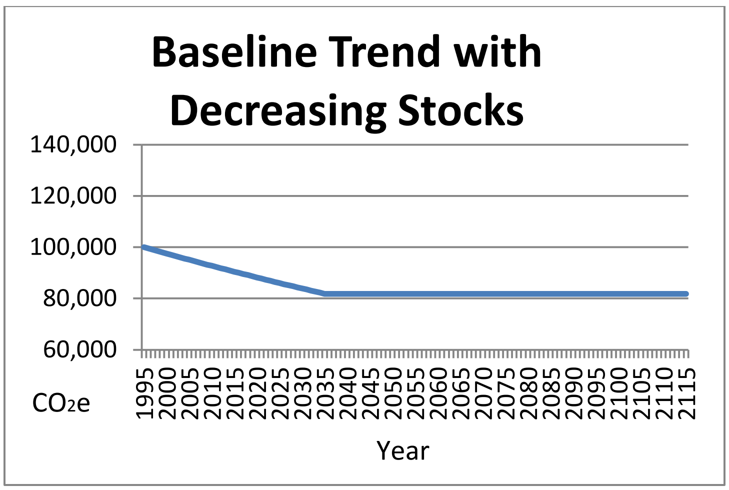


Figure 3.5. Example of Decreasing Baseline Trend Extending 20 Years Beyond Current Inventory and then Static for Balance of 100 Years

4 Updating Forest Inventories

Urban forest inventories must be reported to the Reserve on an annual basis. Urban forest inventories are in constant flux due to forest growth and mortality or removal and therefore must be updated on an annual basis for reporting. The inventory must be updated annually through a combination of projecting existing inventory data and/or re-measuring inventory data with an objective of reporting inventory data that reflects actual conditions in the field.

Plot data can be ‘grown’, or projected for a maximum of 10 years, after which additional field work is required to either update the plot data or establish new plots.

It is important to note that the basis of a successful verification depends on alignment (within tolerance bands defined in Section 8 of the protocol) between verifier data and Project Operator data for each randomly selected plot (selected by verifier), therefore these guidelines do not ensure successful project verification. The actual timeframe between plot re-measurement may need to be reduced to less than 10 years if the updates of inventory data prove to be inaccurate on a plot by plot basis.

Since the biomass of sampled trees is determined through the use of equations that are based on diameter (breast height) and total height variables, updating plot data for forest growth can be accomplished through the use of projections of inventory data in the database that mimic the diameter and height increment of trees in the field. An additional resource document posted on the urban forest webpage provides biomass equations for urban forest projects. The references in the resource document may be useful for Project Operators in designing an appropriate mechanism to ‘grow’ their plot data.

Most references address the annual increment of diameter (DBH). Height growth also needs to be addressed to ensure the most accurate comparison of tree records in the database to actual conditions in the field. Heights can be estimated through regression analysis by comparison of measured diameters to measured heights for a given species. It is recommended that, rather than simply relying on the height estimate from the regression analysis, that Project Operators apply the height increment derived from the regression analysis to the height that was measured in the field.

In any case, plot data that is updated to reflect current conditions with the use of predicted increments of height and diameter data, as well as updates for removals, will be used during onsite verifications to compare against verifiers’ field measurements using the sequential sampling techniques described in the verification section. This provision ensures that plot measurements and update processes are within accuracy thresholds.